5: Electricity and Magnetism

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5A: Electrostatics

Note: Our Basic Electrostatics set contains the following: Rods and Cloth, Turntable, and the Electroscope.

5A10. Producing Static Charge

Electrostatic Rods and Cloth (5A10.10) -- Glass rods and silk (positive charge), clear acrylic rods and wool (positive charge), red acrylic rods and wool (negative charge), or rubber and fur (negative charge).

Electrophorus (5A10.20) -- An aluminum disc with an insulating handle is set atop a plastic plate which has been charged by rubbing with a cloth. A finger or grounded wire touched to the top of the plate removes the induced charge that is the same polarity as the charge on the plate, then the disc is lifted off the plate, leaving the disc charged to a high voltage. This may be repeated many times without re-charging the plastic.

5A20. Coulomb's Law

Electrostatic Attraction and Repulsion (Charged Rods on Pivot) (5A20.10) -- Charged rods (5A10.10) on a pivoting stand are free to rotate and show attraction or repulsion between charges. Note: See also Magnetic Attraction and Repulsion (5H20.10).

Aluminized Ping-Pong Balls (Electrically Connected) -- Two aluminized ping-pong balls hang from wires attached to a metal plate. Touch a charged rod to the plate and the balls separate.
Aluminized Ping-Pong Balls (Electrically Insulated) -- Two aluminized ping-pong balls hang from a plastic rod so that they may be given opposite charges to demonstrate attraction.

Three Ping-Pong Balls -- Three aluminized and electrically connected ping-pong balls hang from a common point on thin wires so that they just touch. The balls are now charged with a Wimshurst generator, causing them to fly apart by electrostatic repulsion. A camera is mounted above the ping-pong balls and shows that the direction of the repulsive force is outwards from the center of the three balls.

5A22. Electrostatic Meters

Electroscope (5A22.10) -- An electroscope with the pivoted detector shadow projected onto a translucent glass plate is used to show charge. One can charge the electroscope by direct conduction or by induction (bring a charged rod close to the plate of the electroscope, then touch the plate with your finger. This draws off the free charge. Remove your finger and the rod, and the electroscope is left with an unbalanced charge opposite that of the rod.

Electrostatic Voltmeter (5A22.50) -- A voltmeter which reads the potential near charged rods without affecting the charge.

5A30. Conductors and Insulators

Conducting and Non-conducting "T" (Plastic and Aluminum Rods) (5A30.15) -- A large "T" shaped terminal is attached to the electroscope. One arm is made of acrylic and the other arm is aluminum, but both have a metal ball on the end. Touch a charged rod to the ball on each arm to show that only the aluminum arm conducts and charges the electroscope. This can also be done with wire and string.

5A40. Induced Charge

Charge By Induction (Induction Spheres) (5A40.10) -- Two metal spheres on insulated stands are touching each other. A charged rod is brought near one of them which induces the opposite charge on the other sphere. While the rod is held close to the first sphere, the other is moved away and touched to the electroscope.

Wooden "Needle" (5A40.30) -- A wood 1x2 is placed on a rotating stand, and will be attracted by either a positively or negatively charged rod due to induction and polarization of the charge within the wood.

Metal Rod on Pivot (5A40.35) -- A metal rod on a rotating stand will be attracted to a charged rod of either sign due to induced charge in the metal rod.

Deflection of a Water Stream (5A40.40) -- A charged rod deflects drops of water. Note: This is hard to see in a large class.

Kelvin Water Dropper (5A40.70) -- An unusual induction machine in which dripping water acts as the carrier for charge buildup in two metal cans. When a sufficiently high voltage is reached, the cans discharge through a small neon lamp. Note: This is hard to see in a large class.

5A50. Electrostatic Machines

Wimshurst Machine (5A50.10) -- A small hand-cranked generator produces sparks in the hundred-kilovolt range; in principle a continuously operating electrophorus (see 5A10.20).

Van de Graaff Without Streamers (5A50.30) -- A commercially made Van de Graaff machine; used for a number of demonstrations,
including the classic stand-your-hair-on-end. Note: Talk to us in advance about how to do this hair-raising demo. Using paper
streamers instead of hair works much better.

See also Van de Graaff With Streamers (5B10.15).

**Toeppler-Holtz Machine** -- Large 200 - 300 kV discharges from this antique generator (c. 1895) are very impressive, but please give us a
couple hours notice in order to pre-charge it beforehand. Specific demos include: Lightning Rod (5B30.30), Point and Candle (5B30.40),
Pinwheel (5B30.50). Caution: Crank slowly!

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**5B: Electric Fields and Potential**

**5B10. Electric Field**

**Van de Graaff With Streamers (5B10.15)** -- A Van de Graaff generator with long paper streamers attached to the dome is used to
show the radial shape of the electric field produced by the machine; one can also show the distortion of the field due to the
introduction of a grounded metal rod. Note: This works much better than getting a student's hair to stand up.

**Bouncing Ping-Pong Balls (5B10.30)** -- A variation of Franklin's Bells. Conductive ping-pong balls bounce up and down between two
charged metal plates due to electrostatic forces on the balls. Also shows basic charge transfer. Note: This uses the same setup at the
Millikan Oil Drop Analog.

**Grass Seed Electric Field (5B10.40)** -- Variously shaped electrodes are placed in a transparent basin filled with mineral oil and a small
amount of grass seed. When a Wimshurst machine is connected to the electrodes and cranked, the shape of the resultant electric field
is shown (on the overhead projector) by the orientation of the grass seed along the electric field lines.

**5B20. Gauss' Law**

**Gaussian Surfaces (Show & Tell)** -- Show and tell items of various geometries for point, line, and plane charge distributions.

**Faraday Ice Pail (5B20.10)** -- Shows that charge resides only on the outside of a conductor. A metal trash can is charged using a
Wimshurst machine, then the charge distribution on the can is investigated using a metal ball on an insulating rod. The ball is inserted
into the can, touched to the inside, then brought out and touched to the electroscope, which does not deflect. If the outside of the can
is touched, however, the ball collects charge which can be transferred to the electroscope, causing deflection. On a dry day this can be
repeated many times. Please practice this beforehand!

**Faraday Cage (5B20.30)** -- A large mesh grounded wire cage fits over the electroscope, shielding it from outside electrostatic effects. A
high voltage source (a charged acrylic rod) brought near the cage will not deflect the electroscope.

**Radio in a Faraday Cage (5B20.35)** -- A small radio is placed in a copper wire mesh cage. Note: The lecture halls themselves
sometimes act as large Faraday cages and block all radio transmissions.

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**5B30. Electrostatic Potential**

**Egg-Shaped Conductor (5B30.20)** -- Show and tell item used to discuss charge density as a function of radius of curvature.

**Van de Graaff and Wand (5B30.35)** -- A grounded wand with a round bulb on one end and a sharp point on the other is brought near
a charged Van de Graaff. The bulb end draws out impressive sparks, while the pointed end produces only corona discharge.
Note: The following three demonstrations are all done on the Toepler-Holtz machine. Please give us plenty of advance notice in order to charge it beforehand.

**Lightning Rod (5B30.30)** -- A model house with a conductor in the chimney is placed on the Toepler-Holtz machine. One electrode of the machine connects to the chimney, the other to a “cloud” suspended directly above the chimney. When the machine is cranked, impressive sparks between cloud and chimney simulate lightning bolts striking the house. A sharp-pointed lightning rod (which is electrically connected to the chimney) is then pushed up out of the top of the house, and the resulting corona discharge stops the “lightning” immediately.

**Point and Candle (5B30.40)** -- A burning candle brought near a sharp point attached to the Toepler-Holtz machine is nearly blown out due to the electrostatic repulsion on the ions in the flame and the coronal wind from the point. By comparison, holding the candle near the large ball electrode to which the point is attached produces a much smaller effect.

**Pinwheel (5B30.50)** -- A pinwheel with sharp points at the ends of the arms is mounted so as to spin horizontally on one of the electrodes of the Toepler-Holtz machine. When the machine is cranked, the corona discharge from the points causes the pinwheel to spin.

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**5C: Capacitance**

**5C10. Capacitors**

**Sample Capacitors (5C10.10)** -- Show and tell capacitors of many types and sizes.

**Parallel Plate Capacitor (Variable Separation) (5C10.20)** -- Two parallel circular metal plates which form a capacitor are supported so that the distance between them can be varied. The plates are connected to an electrostatic voltmeter and charged. As the separation varies, the changing voltage between the plates is reflected in the reading on the voltmeter. See Parallel Plate Capacitor with Dielectrics (5C20.10).

**Battery and Separable Capacitor (5C10.21)** -- A parallel plate capacitor with its plates separated by a thin mica sheet is hooked to the electroscope and charged with a 90 V. battery. The plates are pulled apart, and the decrease in capacitance raises the voltage enough to deflect the electroscope, showing that battery electricity and static electricity are one and the same.

**Tuning Capacitor (Variable Area) (5C10.35)** -- Similar to the Parallel Plate Capacitor (5C10.20), but this is a large version of the tuning capacitor used in AM radios, in which the area (overlap) between the plates can be changed.

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**5C20. Dielectrics**

**Parallel Plate Capacitor with Dielectrics (5C20.10)** -- Uses the same setup as the Parallel Plate Capacitor (5C10.20), but instead of varying the separation a large plastic or cardboard sheet is inserted between the plates while they are charged, and the changing voltage is noted.

**Force on a Dielectric (5C20.20)** -- A circular plastic disk on the end of a seesaw arm is balanced between and slightly above the plates of a large parallel plate capacitor. As the capacitor is charged, the force on the dielectric pulls it down between the plates.

**Dissectable Leyden Jar (5C20.30)** -- A Leyden jar with removable inner and outer conductors is charged with a Wimshurst machine, then discharged through an insulated metal rod - a large spark is observed. The Leyden jar is charged again, then disassembled by
removing the inner and outer conductors. These can be touched together, grounded, etc., and no sparks are seen. However, if the Leyden jar is now reassembled and discharged with the metal rod, a discharge occurs which is almost as large as the first. Note: Please see us beforehand about technique.

5C30. Energy Stored in a Capacitor

**Leyden Jars on the Toepler-Holtz (5C30.10)** -- Basic demonstration of the ability of capacitors to store energy. The Toepler-Holtz machine is first run without the Leyden jars, and frequent but weak sparks are observed. The Leyden jars are then hooked to the electrodes of the machine, and the discharges become less frequent but much more powerful.

**Exploding Capacitor (5C30.20)** -- Three 1500 mF capacitors connected in parallel are charged to 400 volts. The capacitors look innocent enough after being charged, but lay a discharge strip across the terminals and the resulting BANG! will wake up that guy in the back row, and teach the students that capacitors are a potential danger (sorry).

**Charge vs. Voltage (5C30.37)** -- A small capacitor is charged at 1.5V, then discharged through a projection ballistic galvanometer, the amount of deflection of the galvanometer giving an indication of the charge the capacitor held. The same capacitor is then charged to 3V, and the deflection of the galvanometer upon discharge is approximately doubled.

**Series and Parallel Capacitors (5C30.42)** -- Two identical capacitors mounted on a vertical board which may be used singly or hooked together in series or parallel with copper strips are charged with a battery. After a combination has been charged (to 1.5 V) it can be discharged through a projection ballistic galvanometer, and the amount of charge the combination held is reflected in the reading from the galvanometer.

5D: Resistance

5D10. Resistance Characteristics

**Sample Resistors (5D10.10)** -- Various types, values, and power ratings.

**Rheostat** -- A slide-wire or coil rheostat can be used to discuss the principles of a variable resistor.

**Decade Box** -- A commercial decade resistance box.

**Resistance Wires (5D10.20)** -- One board containing five wires of different lengths, areas, and materials. Each of the wires is hooked in turn across a battery and the current through the wire is shown on a large ammeter. The dependence of resistance on length, area, and composition of the wire can be shown. See also Ohm's Law (5F10.10) and Series and Parallel Resistance (5F20.55).

5D20. Resistivity and Temperature

**Coil in Liquid Nitrogen (5D20.10)** -- A lamp in series with a resistance coil barely glows at room temperature, but when the coil is dipped in liquid nitrogen its resistance decreases and the bulb lights brightly.

**Heated Wire (5D20.20)** -- A resistance wire in series with a small lamp and an ammeter is heated by a gas flame. The resistance of the wire increases with rising temperature, causing the current to decrease and the lamp to dim.

5D30. Conduction in Solutions

**Conductivity of Solutions (5D30.10)** -- A probe consisting of two metal prongs with 110 V between them is dipped into various
liquids, solutions, etc. If the liquid conducts, current flows and lights a bulb.

**Glowing Pickle (5D30.30)** -- Apply 110 VAC across a pickle and it lights at one end. Note: This demo will stink up the whole room.

**5D40. Conduction in Gases**

**Jacob's Ladder (5D40.10)** -- A classic electrical display often seen in the background of mad-scientist B movies. Two long vertical electrodes are close together at the bottom, but separate gradually towards the top. 15,000 Volts from a transformer starts an arc at the bottom. Since the voltage is AC, the arc breaks as the voltage goes back to zero; and the ionized air that was heated during the arc rises while the arc is off. When the AC voltage again becomes high enough to strike an arc, it goes through the ionized air that has risen above the point of the previous arc. The process continues until the arc reaches the top of the electrodes, where it breaks off and reforms at the bottom to begin the cycle again.

**Thermionic Emission (Edison Effect) (5D40.42)** -- The current across a tube diode is measured as the applied voltage is increased, and it is found that no current will pass until the cathode has been heated by the cathode coil. Demonstrates the basic principle of the tube diode.

**Neon Lamp (5D40.50)** -- A neon lamp does not conduct below 80V, but passes current easily above that voltage, and will continue to carry current down to about 60 volts once the current has been started.

**X-ray Ionization (5D40.80)** -- Discharge a charged electroscope with X-rays.

**X-ray Absorption** -- Interpose a lead sheet between the X-ray source and the electroscope and the electroscope discharges more slowly.

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**5E: Electromotive Force And Current**

**5E20. Electrolysis**

**Electrolysis of Water (5E20.10)** -- DC passed through slightly acidic water produces hydrogen and oxygen at the electrodes. Matches are provided to ignite the Hydrogen.

**5E30. Plating**

**Copper Electroplating (5E30.20)** -- Copper and carbon electrodes in a glass container of copper sulfate are supplied with current from a DC power supply to copper plate the carbon electrode.

**5E40. Cells and Batteries**

**Sample Batteries** -- Various types and capacities.

**Electroplate Battery** -- Copper and carbon electrodes in copper sulfate will act as a battery (as shown on a voltmeter), but if the carbon is subsequently plated with copper, battery action ceases.

**Human Battery (5E40.20)** -- Cu and Zn electrodes attached to a galvanometer and touched to the tip of the instructor's tongue produce a current.

**Simple Lead Storage Cell (5E40.60)** -- Two lead plates in sulfuric acid may be charged with a battery eliminator, then discharged
through a small bell. The longer the cell is charged, the longer the bell rings.

**Internal Resistance of Batteries (5E40.75)** -- Voltage from two sets of dry cells (old and new) are measured for an open circuit and a closed circuit with a load. Both sets show a voltage on an open circuit. For the fresh set of cells, voltage does not drop significantly when the load is added, but for the old set of cells with high internal resistance the voltage drops to practically zero.

**Opposing EMF's** -- Batteries are hooked together backwards to show the subtractive effect of opposing EMF's.

**5E50. Thermoelectricity**

**Thermocouple (5E50.10)** -- Current registers on a milliammeter when this large twisted wire thermocouple junction is heated in a flame.

**Thermoelectric Magnet (5E50.30)** -- Heat and cool opposite sides of a large thermocouple. Suspend a large weight from an electromagnet powered by the thermocouple current.

**Thermoelectric Heat Pump (5E50.60)** -- Mount aluminum blocks with digital thermometers on either side of a Peltier device. Run the current both ways.

**5E60. Piezoelectricity**

**Piezoelectric Sparker (5E60.20)** -- a piezo crystal sparker that can be used to charge an electroscope.

**Piezoelectric Gas Lighter with Neon Lamp (5E60.21)** -- The piezo element in a modified gas fire starter develops sufficient voltage to flash a neon lamp.

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**5F: DC Circuits**

**5F10. Ohm's Law**

**Ohm's Law (5F10.10)** -- Uses the Resistance Wires (5D10.20) board described above, but in this demo the voltage is also varied, so that the dependence of current on voltage and resistance can be shown.

**5F15. Power and Energy**

**Voltage and Current in House Lines (5F15.40)** -- A bank of lamps and heaters are hooked up in parallel to 120 VAC. A switch on each allows them to be turned on and off independently. As each element is added to the circuit, the voltage and current flowing into the circuit are displayed on meters to allow calculation of power consumption. A fuse and/or circuit breaker may be added to the circuit to show the function of such safety devices, and the current may also be run in on an iron wire which will overheat and burn a paper rider if the breakers are bypassed and the "safe" current limits are exceeded. A good way to teach students not to stick pennies in fuse sockets!

**Circuit Breaker** -- A standard household magnetic breaker which will shut off current to a load if the current exceeds approximately 3 Amps.

**I2R Losses (5F15.45)** -- A nichrome wire, an iron wire, and a copper wire are hooked up in series with a Variac. A small paper rider is wrapped around each wire. As the voltage is increased, the wires begin to heat up in order of decreasing resistance. Although the current (and thus I2) is the same for all wires, the wire with the greatest R (nichrome) heats up first and burns its paper rider.
Increasing the voltage (and current) further makes the iron wire burn the paper and makes the nichrome glow red-hot. The copper wire barely gets warm.

5F20. Circuit Analysis

**Sum of IR Drops (Kirchoff's Voltage Law) (5F20.10)** -- Three large variable resistors are hooked in series with a battery. The voltage drop across each resistor is measured with a voltmeter, and the sum of the IR drops is found to equal the battery voltage. The battery voltage may be varied.

**Conservation of Current (Kirchoff's Current Law) (5F20.16)** -- Current entering and leaving a circuit node can be read on three ammeters, and compared to show that current coming in is always equal to current going out of the node. Can also be used as a two-loop circuit to show the applications of Kirchoff's laws to analyze current flow in a slightly complex circuit.

**Slide-Wire Potentiometer (5F20.30)** -- Classic highly accurate voltage measuring device.

**Wheatstone Bridges (5F20.40)** -- Devices which measure resistance by balancing voltage drops over two different paths, one of which includes the resistor to be measured. Three types are available: (1) With Lamps - a demo item to show the principle but not make actual measurements, (2) With Slide-Wire - to make actual measurements, and (3) Commercial Bridge - a show-and-tell item.

**Series and Parallel Light Bulbs (5F20.50)** -- Two sets of three light bulbs, one hooked up in parallel and the other in series, will clearly show the different current in the two circuits by the relative brightness of the bulbs.

**Series and Parallel Resistance (5F20.55)** -- Two identical resistance wires on a board are hooked across a battery, either singly, in series, or in parallel, and the resulting current for the different hookups is measured with an ammeter.

**Resistor Cube** -- Twelve identical resistors are soldered together to form the edges of a cube, whose resistance can be measured across an edge, a face, or across the entire cube from corner to corner.

5F30. RC Circuits

**RC Charging Curve on Scope (5F30.20)** -- An oscilloscope is hooked across a capacitor which is in series with a battery and resistor. When the switch is closed the capacitor begins to charge and the rising voltage is seen on the scope. Releasing the first switch and pressing another discharges the capacitor, with the resulting discharge curve shown on the scope. Circuit elements are laid out on a vertical board for easy viewing and analysis.

**RC Circuit Analog** -- A flat disc tied to the end of a spring is submerged in a large glass jar of water. Pull up suddenly on the end of the spring and the disc will rise in the water, quickly at first then more slowly as it approaches equilibrium, just as does the RC circuit described above. The spring is analogous to the capacitor in the RC circuit - pulling on it suddenly is the same as applying a sudden voltage - and the resistance of the water to the motion of the disc is the analogue of the electrical resistance in the circuit. The distance that the disc moves is the analogue of capacitor charge.

**Relaxation Oscillator (5F30.60)** -- A capacitor, resistor, and 90V battery are hooked in series, with a neon bulb in parallel with the capacitor. The capacitor charges to about 80V (the breakdown voltage of the neon bulb), then discharges through the bulb and begins the cycle again. The capacitor voltage curve can be displayed on an oscilloscope.

**Emergency Flasher** -- A commercial emergency flasher uses a 9V battery to flash a neon lamp at approximately 2 Hz. (Battery voltage is stepped up internally to provide the 600 volts needed to flash the tube).
Strobe Light -- A commercial strobe light with variable frequency flash.

5F40. Instruments

Galvanometer as Ammeter and Voltmeter (5F40.20) -- A galvanometer is used with shunt and series resistors.

5G: Magnetic Materials

5G10. Magnets

Lodestone (5G10.16) -- A rock formed of magnetite, a naturally-occurring magnetic mineral. Color-coded with North and South poles.

Broken Magnets (5G10.20) -- A broken bar magnet held together by its magnetism acts as a single magnet when whole. It can be pulled apart into two or more pieces and their fields traced with compasses and/or iron filings to show that each piece is also a complete magnet.

5G20. Magnetic Domains and Magnetization

Barkhausen Effect (5G20.10) -- A soft iron core is surrounded by a pickup coil. Bringing a permanent magnet near causes domains in the iron to flip, which is picked up by the coil and amplified into a crackling, rushing noise.

Magnetic Domain Model (5G20.30) -- A plastic plate holds small bar magnets on bearings which simulate domains - they line up with one another, flip in the presence of an external field, etc. Use on the overhead projector.

Permalloy Bar in Earth's Field (5G20.55) -- A permalloy rod (iron and nickel) is not itself magnetic but has a high magnetic permeability. If the rod is aligned with a pre-existing magnetic field such as the Earth's or a magnet's, it becomes magnetic enough to pick up small pieces of iron.

Huesler Alloy -- An alloy of manganese, aluminum, and copper is attracted to a magnet even though none of its constituent metals is magnetic by itself.

Electromagnet with 1.5 Volt Battery (5G20.70) -- A small electromagnet powered by a 1.5V battery that can hold several kilograms.

Big Electromagnet (5G20.72) -- A huge coil carries up to 25A; very strong field will attract nails, etc. that are thrown near. Nail on a string allows the shape of the field to be probed, and the removable iron core concentrates the magnetic flux. Note: See also Lamp in Parallel with a Solenoid (5J20.20).

5G30. Paramagnetism and Diamagnetism

Paramagnetism and Diamagnetism (5G30.15) -- Test tubes filled with manganese chloride, copper sulfate and bismuth are balanced at opposite ends of hanging bars which are free to rotate. Bring a powerful horseshoe magnet near the manganese chloride (paramagnetic) and it will be pulled slowly into the magnet. The copper sulfate (also paramagnetic) will be less strongly attracted to the magnet. Bismuth (diamagnetic) will be slightly repelled.

5G40. Hysteresis

Hysteresis Waste Heat (5G40.50) -- A thimbleful of water sits atop the secondary coil of a transformer. Waste heat from eddy currents and magnetic hysteresis boils the water.
Heated Canadian Nickel (5G50.15) -- Nickel (Curie temp: 358 °C) is magnetic at room temperature and non-magnetic when heated with a gas torch. A Canadian nickel hangs from a wire and is initially suspended by a strong magnet. After heating, the nickel falls away from the magnet.

Dysprosium with Liquid Nitrogen (5G50.25) -- Dysprosium (Curie temp: -188 °C) becomes magnetic when cooled with liquid nitrogen. A piece of dysprosium hangs freely at room temperature. After cooling it is attracted to a strong magnet, but falls away as it warms up.

The above two demonstrations work nicely together.

Curie Temperature Wheel (5G50.20) -- A rotating wheel (made of 70% iron and 30% nickel) passes through the poles of a magnet, and has a Curie point slightly above room temperature. A spot on the wheel directly above the magnet is heated with focused light and loses its magnetic properties. The spot directly below the magnet is then drawn upwards and the wheel begins to revolve. By the time the first hotspot makes a complete circle, it has cooled enough that the spinning is continuous.

Meissner Effect (Superconductor Levitation) (5G50.50) -- A LN2 cooled ceramic superconductor (Yttrium Barium Copper Oxide, YBa2Cu3O7) will levitate a small rare-earth magnet due to induced eddy currents in the superconductor.

5H: Magnetic Fields And Forces

5H10. Magnetic Fields

Compass (5H10.11) -- Large arrow compass to demonstrate Earth's field, field around magnets, solenoids.

Dip Needle (5H10.15) -- The compass above may be oriented vertically along a North-South line to serve as a large dip needle to show the angle of declination of the Earth's field.

Oersted's Needle (5H10.20) -- A compass is brought near a wire carrying a large current. Or a compass is set near the wire with the DC power supply turned off. When the power supply is turned on, the compass will reorient itself to be perpendicular to the current.

Magnetic Fields Around Magnets on Overhead Projector (5H10.30) -- Iron filings on a plastic shield are placed on the overhead projector and used to show the shape of the field around bar and horseshoe magnets. Small transparent compasses are also available to show the sense of the field.

Magnetic Shielding (5H10.61) -- Various metals, etc. are inserted between an electromagnet and some nails the magnet is holding up. Materials that are magnetic (iron) absorb the magnetic flux, allowing the nails to fall - nonmagnetic materials don't. A double thickness of iron causes more nails to fall. Warning: We're not sure how reliable this demo is.

5H15. Fields and Currents

Magnetic Fields Around Conductors on Overhead Projector (5H15.10) -- Bare wires in various configurations on transparent boards carry a large current; board is placed on overhead and sprinkled with iron filings to show shape of the field. Small transparent compasses can be used to show the sense of the field.
5H20. Forces on Magnets

Magnetic Attraction and Repulsion (Bar Magnets on Pivot) (5H20.10) -- Bar magnets on a pivoting stand show attraction and repulsion. Note: See also Electrostatic Attraction and Repulsion (5A20.10).

Levitron (5H20.22) -- A spinning magnetic top that levitates stably (sort of) above a large permanent magnet. It takes some adjustment to get it working right, so please give us lots of notice and be prepared to practice beforehand.

5H25. Magnet/Electromagnet Interaction

Hanging Solenoid and Bar Magnet (5H25.10) -- Free-hanging solenoid interacts with a pivoting bar magnet only when the current is on. The interaction is weak at first, but is much stronger with the iron core in place.

5H30. Force on Moving Charges

Electrostatic Deflection of an Electron Beam (Oscilloscope) -- An external DC power supply is connected to either the vertical or horizontal plates of the open oscilloscope. Changing the applied voltage changes the deflection of the electron beam.

Magnetic Deflection of an Electron Beam (Open Oscilloscope) (5H30.10) -- An electron beam is deflected by the field from a bar magnet.

Magnetic Deflection of an Electron Beam (Crooke's Tube) (5H30.15) -- An electron beam is deflected by the field from a bar magnet.

Fine Beam Tube (5H30.20) -- An electron beam in an evacuated glass sphere is bent into a circle by the magnetic field from a pair of large Helmholtz coils. The beam is faintly visible in a dark room because of collisions with a tiny amount of helium in the tube.

Thomson's E/M Experiment -- An electron beam in an open oscilloscope is vertically deflected by an electric field, then by a transverse magnetic field which balances the electric field and reduces the deflection to zero. Ratio of electron charge to mass could then be calculated from the values for deflection and field intensities, but the demo is usually only done qualitatively.

Ion Motor (Force on Ions) (5H30.55) -- Cork particles floating in a solution of copper sulfate in a circular container will rotate when current is passed through the solution in the presence of a magnetic field. Reverse either the current or the magnets to reverse the direction of the solution and cork. Remove the magnets and the solution and cork will slowly come to rest.

5H40. Force on Current in Wires

Pinch Wires (5H40.20) -- Parallel hanging wires are either attracted or repelled by one another, depending on the direction of currents in the wires. Three different configurations.

Jumping Wire (5H40.30) -- A single thick wire passes between the poles of a powerful horseshoe magnet. When a heavy duty DC power supply is turned on, the wire jumps out of the field.

Barlow's Wheel (Video Only!) (5H40.50) -- A flat disk of aluminum on bearings whose bottom half passes between the poles of a powerful magnet. A large DC current runs from the center to the bottom point of the disk, and the force on the electrons flowing through the magnetic field causes the disk to rotate. Note: This demo is no longer in service, due to concerns over the exposed mercury involved in its operation. It is however, available on our laser disk collection.
Ampere's Frame (Video Only!) (5H40.70) -- A square frame of aluminum rod, free to rotate, through which a large DC current flows. A magnet brought near one side of the frame causes rotation (in a direction predicted by the right hand rule). Note: This demo is no longer in service, due to concerns over the exposed mercury involved in its operation. It is however, available on our laser disk collection.

5H50. Torques on Coils

D'Arsonval Meter (Model Galvanometer) (5H50.10) -- A large open model of an galvanometer. A large coil on spring-mounted bearings twists in the magnetic field of a magnet when current flows in the coil.

5J: Inductance

5J10. Self Inductance

Inductors (Show and Tell) (5J10.10) -- Various commercial and homemade coils.

5J20. LR Circuits

LR Circuit (5J20.10) -- A large inductor in series with a resistor, a battery and a switch. When the switch is closed the current rises slowly from zero to a steady-state value as shown by the voltage across the resistor.

Lamp in Parallel with a Solenoid (5J20.20) -- A large DC current introduced suddenly to this large inductor cannot pass through the coil at first, so an incandescent lamp in parallel with the coil lights brightly. After the current becomes steady, the coil draws more current and bulb dims. When the current is switched off suddenly, the induced voltage in the coil (back EMF) again lights the lamp. A separate neon lamp in parallel with the coil shows that the direction of the second voltage surge is the opposite of the first.

5J30. RLC Circuits - DC

Damped LRC Oscillation (5J30.11) -- The capacitor in an LRC circuit is fully charged with a battery, then the battery is removed, a switch is closed and the circuit is allowed to oscillate down to equilibrium. Voltage across the capacitor is displayed on the scope as the oscillations die away.

5K: Electromagnetic Induction

5K10. Induced Currents and Forces

Wire and Magnet (5K10.15) -- A single loop of wire is passed between poles of a large horseshoe magnet, causing current to flow (shown on a galvanometer). The faster the wire is moved, or the greater the number of loops, the larger the current.

Coil Pendulum in Magnet (5K10.18) -- A pendulum with a large coil for a bob swings between the poles of a large horseshoe magnet. A small light bulb wired to the coil flashes when the coil swings through the magnetic field.

Simple Coil and Bar Magnet (5K10.20) -- A coil is connected to a galvanometer. A bar magnet is passed through the coil and the galvanometer measures the current.

10/20/40 Turn Coils with Magnet (5K10.21) -- Coils of 10, 20, and 40 turns wired in series on a common stand, through which a permanent magnet is moved to produce small currents as shown on a galvanometer.
Mutual Induction (5K10.30) -- Two coils slide on a track so that the distance between them can be varied. Current is pulsed into one coil with a switch, which induces current in the second coil. Meters show the currents in both coils, and show that there must be a changing current in the first coil to induce current in the second. Intensity of induced current changes with separation, and various metal cores can be inserted to determine their effect on the magnetic flux.

Earth Coil (5K10.60) -- A hand-held coil is moved in the Earth's magnetic field and produces a current (must be shown with projection galvanometer).

5K20. Eddy Currents

Eddy Current Pendulum (5K20.10) -- A flat plate of aluminum on the end of a pendulum swings between the poles of a magnet. Eddy currents in the plate damp out the swing. Both a plate and a ring are available, split and unsplit. The split limits the size of the eddy currents and greatly decreases the damping in both plate and ring.

Eddy Current Brake (5K20.22) -- A motorized spinning aluminum disk can be slowed down by slipping the poles of a magnet over the edge.

Eddy Current Free Fall (5K20.25) -- A magnet and a piece of brass slide down either a length of aluminum channel or copper pipe. The copper pipe has a much stronger effect but is less visible than the aluminum channel.

Thompson's Flying Ring (Jumping Rings) (5K20.30) -- AC in a large solenoid creates eddy currents in an aluminum ring and the ring goes flying; a split ring does not. Also includes rings made of iron and copper. This uses the same setup as Vertical Primary Coil and Secondary Coils with Lamps (5K30.30).

Arago's Disk (5K20.42) -- An aluminum disk spins beneath a magnet on bearings, causing the magnet to rotate due to eddy currents in the plate. The magnet may be restrained by a rubber band to make a model of a speedometer linkage.

Spinning Can -- A large horseshoe magnet is spun over an aluminum can sitting on a pivot. The can spins in the same direction as the magnet due to eddy currents from the rotating magnetic field.

5K30. Transformers

Ferromagnetism (Rowland Ring) -- Show and tell simple transformer.

Transformers (5K30.20) -- Two coils sit on a common iron core. AC is fed into one coil, and the magnitude of the voltage in the second coil is shown by the brightness of a lamp. Turn ratios can be 1:1, 2:1, or 1:2.

Transformer Laminations -- A transformer core that has been pulled apart to show the individual laminations.

Vertical Primary Coil and Secondary Coils with Lamps (5K30.30) -- A tall primary coil that carries AC has an iron core which extends out of the top. Two secondary coils with different numbers of turns can be placed on top to light a small or large light bulb. Same setup as Thompson's Flying Ring (Jumping Rings) (5K20.30).

Transformers and Power Lines -- A step-up transformer with a turn ratio of 250 to 1000 converts 110 Volts from the wall (indicated by a 60 Watt bulb) into over 400 Volts. This is transmitted 30 feet across the width of the room (with a couple high resistance rheostats simulating hundreds of miles of power line) to an indentical step-down transformer and a second 60 Watt bulb. Start with both transformers disconnected to show the huge power loss over the long distance (the second bulb will be dim). Then connect
both transformers and the second bulb will be nearly as bright as the first.

5K40. Motors and Generators

**DC Motor (5K40.10)** -- A large open coil powered by DC current through a split-ring commutator spins between the poles of a set of permanent magnets. See also AC and DC Generator (5K40.40).

**Faraday Disk Dynamo (5K40.15)** -- An aluminum disk spinning between magnet poles produces a current between the center and the edge of the disc as shown on a large galvanometer.

**AC and DC Generator (5K40.40)** -- A large model generator with a coil spinning between permanent magnets. Can produce DC (split-ring commutator) or AC (solid ring) current. Good visibility. Can also be run as a DC Motor (5K40.10).

**Army Surplus Generator (5K40.80)** -- A hand-cranked generator will provide up to 60 watts of output power for an incandescent light bulb. Use the Hand Crank Generator with Lamp if you're interested in showing/feeling the back EMF.

**Hand Crank Generator with Lamp** -- A small crank generator lights lamp - easier to turn with the bulb out of the socket.

**Genecon Generators** -- Two small hand cranked generators can be connected to each other (spin one and the other will spin as well), or to a small light bulb.

**Falling Weight Generator (5K40.85)** -- A weight on a string wrapped around the shaft of a generator falls more slowly when there is an electrical load on the generator.

5L: AC Circuits

5L10. Impedance

5L20. RLC Circuits - AC

**Driven LRC Circuit (5L20.18)** -- A LRC circuit is driven by a 60 Hz input, and the resulting voltage and current across any component can be displayed on an oscilloscope. I and V are tested by means of a probe that plugs into a highly-visible schematic board which shows the electrical location of the probe. All components can be varied to determine the effect on resonance as shown by the voltage on the screen. Phase shifts between I and V may be shown for each component.

5L30. Filters and Rectifiers

**Rectifier Circuit (5L30.10)** -- A diode rectifier circuit mounted on a vertical board can be probed at different points with an oscilloscope to see the effect of diode rectification on an AC voltage. Filtering elements at the output end of the circuit may be switched in and out to demonstrate the smoothing of ripples in the DC output.

5M: Semiconductors And Tubes

5M10. Semiconductors

**Hall Effect Probe (5M10.10)** -- Shows the voltage developed at right angles to a current in a conductor in a magnetic field; as used in Gaussmeters.
Solar Cells -- A small bank of solar cells hooked to a milliammeter produce current, increasing with brighter light.

Electroluminescent Panel -- A solid state panel glows with a pale green light when energized by the proper voltage.

5M20. Tubes
Tube-Style Radio Circuit -- An old style radio circuit laid out schematically shows the function of various parts of the circuit.

Large Radio Tubes -- 30cm tall amplifier tubes may be shown with a modern transistor to show advancement of the technology.

See also Thermionic Emission (Edison Effect) (5D40.42).

5N: Electromagnetic Radiation
5N10. Transmission Lines and Antennas
Radio and Charging Rod -- A plastic rod is charged by rubbing it vigorously with a wool cloth. The small discharges between the rod and the cloth give off electromagnetic noise that can be picked up on an AM radio.

Cenco 3-meter Transmitter (5N10.60) -- A small tube-style dipole transmitter sends radio waves to a pickup antenna, lighting a small bulb in the center of the antenna. Moving the antenna away from the transmitter dims the bulb, and rotating the antenna at right angles extinguishes the bulb, showing the polarized nature of the radio waves.

EM Spear (5N10.80) -- A large rolling model of an electromagnetic wave shows the relation between electric and magnetic field vectors.

5N20. Tesla Coil
Induction Coil (5N20.10) -- A standard induction coil with mechanical "make and break" oscillator produces approximately 100,000 V.

Tesla Coil (5N20.50) -- Tesla air-core resonant transformer produces 1/2 million volts at 350 kHz.

Hertzian Waves -- A spark transmitter has two large resonant circuits (jar capacitor and resistance) tuned to the same frequency - transmitter circuit is powered by a spark coil, receiver picks up electromagnetic waves emitted and lights a neon bulb. Receiver can be detuned to show decreased efficiency.

5N30. Electromagnetic Spectrum
White Light Spectrum (5N30.10) -- Project white light through a high dispersion prism.

Ultraviolet Spectrum (5N30.15) -- White light from a carbon arc lamp falls on a screen of half white paper and half fluorescent paper.

Microwave Transmitter and Receiver Set (Brett's Microwave Apparatus) (5N30.30) -- A microwave emitter and receiver are mounted on a vertical circular board. The emitter is stationary, while the receiver is free to rotate with the board. A bar-graph display mounted on the board shows the intensity of the microwave signal picked up by the receiver as it is moved around. Note: Please specify which of the following effects you would like to show:
• Straight Line Propagation
• Reflection from Flat Surfaces (See 6A10.18)
• Refraction
• Single Slit Diffraction (See 6C10.50)
• Double Slit Interference (See 6D10.20)
• Multiple Slit Interference
• Waveguide
• Interferometer (See 6D40.20)
• Polarization (See 6H10.20)
• Bragg Diffraction (See 7A60.50)
• Total Internal Reflection
• Barrier Penetration (Tunneling) (See 7A50.20)